About the Nature of Gravitational Constant and a Rational Metric System.

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About The Nature of Gravity Constant and Rational Metric System

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"We are to admit no more causes of natural things that such as are both true and sufficient to explain their appearances."
[Newton]

Abstract

The gravitational constant G has been a subject of interest for more than two centuries. Precise measurements indicate its equal to $6.673(10)\mathrm{x}10^{-11}$ $m^3/(kg\ s^2)$ with relative standard uncertainty of $1.5\mathrm{x}10^{-3}$[1]. The need for such constant is discussed. Various system of units of measure have emerged since Newton, and none of them is both practical, and useful in theoretical research. The relevance of a metric system that only has length and time as base units is analysed and such system proposed. As a result much higher clarity of physical quantities is achieved. Gravity constant and electric constant can be eliminated to become non-dimensional, that results in elimination of kilogram of mass and Coulomb of charge in favour of the same composite unit for both physical quantities being m^3/s^2. The system offers a great advantage to General Relativity where only space-time units can be used.

Keywords

Gravitational Constant, units of measure.

1 Introduction

The gravitational constant G is a proportionality factor in Newton's inverse square law of gravitation for a point mass:

$$|F| = G \cdot \frac{m_1 m_2}{r^2}$$

The obvious way to determine this constant is to perform a direct measurement of an attraction force between two masses. This has been accomplished by Cavendish [2], resulting in determination of the mass of the Earth, Sun and subsequently all celestial bodies in the solar system.
According to Newton:

"The qualities of bodies which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever"[3].

This then supports the declaration of the gravitational constant ***G*** as the universal constant – a physical property characterising gravitational phenomena. It is unclear whether ***G*** can be referred as a property of anything. Fundamental physical constants tend to be seen that way. Their names often make it clear. To mention a few we have:

a. speed of light in vacuum,

b. elementary charge

c. electron rest mass

Other constants bear names of famous physicists rather describing their nature such as:

a. Bohr radius,

b. Thomson cross section,

c. Planck length,

d. Compton wave length.

In between there exists Newtonian Constant of Gravitation. The constant that Newton himself never found a particular reason to be identified. Earth mass taken as unit plus astronomical observations are good enough to roughly describe the motion of celestial bodies in our solar system.

A typical description of the Newtonian constant found in textbooks, is by reference to its numerical value equal to force between two unit masses separated by unit distance.
This description is hardly revealing. Force and inertial/gravitational mass are somehow circularly dependent, and force is a complex concept. So ***G*** appears to be a property within a system of at least two material bodies under mutual gravitational interaction.

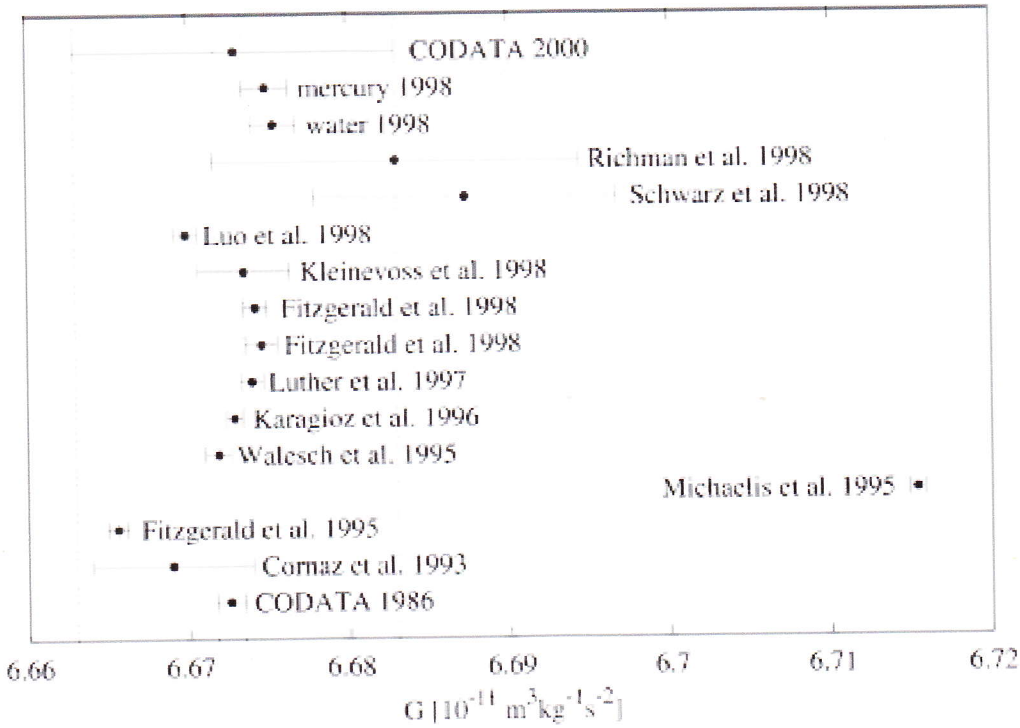
By analogy to dielectric constant clearly expressing varying electrical properties of matter one may say it G does represent a property of some kind. One can certainly say ***G*** makes force equations balance, also its value allows to compare the mass of the Earth with an arbitrary defined unit mass of kilogram. The quest of finding more accurate value of ***G*** continues to this date and no widely acclaimed theory derives its value from any other physical constant, and the nature of it is often referred to as mysterious.

Einstein's General Theory of Relativity (GR) explores gravitation in depth, but it neither predicts nor in fact eliminates the gravity constant, seemingly present in one of the constants necessary to give real world solutions as in formula:

$$\kappa = \frac{8\pi G}{c^2}$$

Numerous speculations exist as whether G is really constant. A number of researches still find differing values of G, which is quite surprising given the increasing precision of measuring equipment and development of more refined experiments.

This fact has been reflected by an unusual decision of CODATA to degrade the relative uncertainty of the official value of G. On the diagram presented below, researchers from University of Zurich [4] show a number of measurements, tolerances and CODATA standarised values.



The gravitational constant as defined in the metric system (SI) is not suitable for astronomical applications according to Fitzpatric[5], G is better expressed in astronomical units where:

The unit of mass is that of the Sun denoted as $M=1$,
The unit of distance is Earth's mean distance to the Sun denoted as $a=1$ and;
The unit of time is one day and the mean period of Earth rotation about the Sun denoted as P.

For such defined units:

$$G = \frac{4\pi^2 a^3}{TM} = \frac{4\pi^2}{365.25638^2}[au^3 m_{sun}^{-1} day^{-2}]$$

Thus G is numerically equal to the mean angular velocity of the Earth in days, therefore somehow related to inverse square of yearly rotation period:

$$\omega^2 = \frac{4 * \pi^2}{T^2}$$

Needless to say that the accuracy of G is the function of accuracy of time measurement (provided that the variation of mass of the Sun can be neglected).

The contemporary science seems to have agreed on universality of G and more common is to find new measuring techniques or hypotheses of its variable nature then attempts to find a suitable explanation of its nature.
Some researches openly raise the issue of its irrelevance. For instance Siepmann[6] says:

"It is readily apparent that the current gravitational constant is not a tangible physical concept as demonstrated by its units of measure which are currently mandatory for the law of universal gravitation to yield the correct units for force. It is a constant that grossly works in most instances but yet we have no understanding of why. This is because we have had an erroneous understanding of gravity."

This author's claim is based on theory referred as "Laws of Space and Observation" and in particular the "Space Constant Equation". Enough to say, it is an alternative concept of space and time on which I am not in a position to comment.
If the claim of physical irrelevance of G was true, then it is believed one can explain the current value of G within the realm of classical physics.

In his work [7][8] Guy Myhre demonstrates how numerical values of universal constants obscure rather than clarify the laws of physics. In [8] he writes:

"It seems to mean that these constants have existed since time began, since the universe was born tens of billions of years ago. Are they fundamental? Are they universal? Are they physical? Are they constant? Do they exist in nature? The answer to all of these questions is NO. So, what are these important-sounding things, anyway? Well, they are simply inventions that were necessary to make quantum-based equations work...when metric units of measure were used (and they always were)[...] As a rule of thumb, if the constant possesses multiple units of measure (dimensions), it is not a fundamental physical constant. One exception is the speed of light..."

Myhre shows in [7], that it is possible to establish a rational system of units that almost renders all fundamental constant void. He uses a hypothetical particle "masstron" to make his system of units closed.
Myhre's work whether controversial or not, makes strong points and it was a significant stimulus to conduct investigations described in this work.

Numerous system of units has been proposed since Newton, such as those originated from Planck or Gauss. And it appears to be a rule that the unit of mass/charge stay as fundamental, irreducible and only scaling is exercised to gain convenient magnitudes of physical quantities for various reasons.

Consistent with the motto presented at the beginning, this work favours the method of simplification of existing concepts rather complicating them relaying on new theories and hypothetical entities. By no means however this statement attempts to invalidate such theories and approaches.

2 The Significance of Metric System Units.

The effect of units of measure selection to the values of physical constants is beyond discussion. The foundation of the metric system was a remarkable achievement preceded by centuries long build-up of human knowledge, then an organisational and intellectual effort to put it in action. The group of people involved in this process included famous figures such as Laplace, Cassini, Talleyrand, to mention a few. Resulting from this effort was the definition of meter, kilogram and second.

The second was arbitrarily defined using period of rotation of the Earth on its axis as 1/86400 of a mean solar day. This is an arbitrary interval, the fraction of 1/(2*12*60*60), convenient enough to design the face of an ordinary clock. More difficult issue is how to calibrate a reference device and how to determine the exact moments the Earth starts and completes its cycle. That task was left to astronomers. Following the discovery of Earth rotation irregularities and new designs of precise clocks, the second had to be re-defined, yet its first concept based original magnitude has been accurately preserved. The current definition of the second is based on Cs133 electron transitions between selected hyperfine energy levels (9,192,631,770 cycles).

The arbitrary nature of 1 second interval is obvious. There is no known law indicating Earth rotation period to be of universal significance. It must have been the result of the state of its composition and surrounding matter at the time of formation. Neither earth's mass nor energy content are believed the have some necessary magnitude.

The selection of the unit of meter was not that arbitrary.

The first widely known prototype of meter according to Bureau International des Poids et Mesuresis was:

"1/10 000 000 of the Northern quadrant of the Paris meridian(1 August 1793)."

This however was not the first notion of meter's physical magnitude. It is reported that in 1671, Picard suggested a unit of length based on a pendulum, replicating period of 1 second.

description of motion one can select an interval of any regular cyclic process as a unit and any reference length and should be able to verify basic equations of motion. The idea of the metric system went beyond simple kinematics as all physics now can be described in the minimum set of units, predominantly length mass and time.

As we know, time and length unit closely relate to the same physical object, that is the Earth. Forgetting the pendulum for the time being, once second is accepted, and the fraction of the meridian defined to be the unit of length, one can say without making a big mistake (assuming the Earth is spherical) that it is not necessary to measure such quantities as:

a. Earth diameter, circumference, surface and volume,

b. Earth tangential rotational speed at the equator and anywhere else,

c. Earth angular velocity and angular acceleration.

In the idealistic scenario (spherical Earth) these quantities can be derived from geometry, simple kinematics and just adopted definition of metric units. It is an important, non-trivial, but a separate problem of how to physically realise such defined reference devices. Until then one can enjoy the metric system by roughly calculating a distance to the Sun in meters by measuring angles to the Sun at noon the same day, from two different latitudes without even knowing how long that meter really is. This task is impossible to accomplish for the unit of foot (well known length) without actually measuring the Earth first.

Due to the fact that standard meter is nicely correlated with the period of one meter pendulum, that is: the experimentally determined length of the string producing 1 second half-period is "exactly" equal to the unit length, we may conclude (in the idealistic scenario) that the gravity acceleration g has been defined as π^2 (rather than measured) at certain distance from the Earth centre. From there, it is only one step to approximate G*M from Newton equation:

- $g=\pi^2$ [m/s^2] – defined coincidently with calibration of the pendulum.
- R=4*10000000/(2*π)[m] – defined but also correlated with pendulum.
- G=?[m^3/kg s^2] – unknown.
- M=?[kg] – unknown.

From this we have:

$$GM = R^2 g = \frac{40000000^2}{4\pi^2} * \pi^2 = 4 \times 10^{15}$$

The best value available from WGS84 sources [10] is GM=.39860009x10^{15} which is in error of 0.3512%.

One thing should be made clear. This is not a suggestion that one can ignore measurements as the ultimate source of usable physical data, but we want to separate concerns of experimental techniques used to verify theories from the theories themselves.

The examples above show that abstract concepts can be qualitatively pursued with the minimum of essential approximate measurements. In many cases theories come earlier than their measured confirmation. A theory is more convincing if experiments confirm its predictions, than that fitted to already known experimental facts. Such remarkable event has occurred for Maxwell equations that predicted electromagnetic waves and their propagation speed.

3 The Relevance of G.

The short answer to the question whether the gravity constant is relevant is yes. More difficult is to define the nature and the domain of relevance. The following analysis will deliberately be performed in accordance with classical physics.

Any two measurable properties whether mutually dependent or not, can be related by an observer through the act of observation. Each property if changes in time, can be plotted one versus another and will result as an instance of experimentally established function. This function may then be represented mathematically. By the fact of existence of functional dependency one cannot derive a conclusion about physical dependency of the two quantities. If however under some experimental conditions one property can be actively changed and it is followed by a correlated response of another, there is a strong evidence of existing dependency. If the two measurable quantities are dependent yet they are of quite different nature, there will be some physical constants involved to make any equation relating them to be dimensionally consistent.

Newton's equation simplified in the form:

$$m_1 \frac{\partial^2 r(t)}{\partial t^2} = -G \cdot \frac{m_1 m_2}{r(t)^2}$$

relates two bodies where the left hand side describes the motion of body 1 due to the cause described by the right hand side. Both sides represent equal forces (as we call them).

Due to cancellation of m_1 we will have

$$\frac{\partial^2 r(t)}{\partial t^2} = -G \cdot \frac{m_2}{r(t)^2}$$

Or in non differential form:

$$g = G \cdot \frac{m_2}{r^2}$$

For the first form, G acts as the property in between the field generator, and the moving system, because of this field. In the second form it is not quite clear.

g can still be seen as the acceleration of the body m_1 due to gravity, yet this acceleration will be the same for any body at a distance r. That implies that the field property is conveniently described through the behaviour of an accelerating body.

To determine the "composition" of G we use simple reference one meter pendulum equation with other relevant quantities using explicit unit length mass and time symbols:

$$2 \cdot s = 2 \cdot \pi \sqrt{\frac{1 \cdot m}{g}};$$

$$g = 1 \cdot m \frac{\pi^2}{1 \cdot s^2}$$

$$m_2 = Me * u_m$$

$$r = Re * m$$

where:

a. s is a generic placeholder for unit second

b. m is a generic placeholder for unit meter

c. u_m is a generic placeholder for unspecified as yet unit of mass

d. Re is the non dimensional number of unit meters in Earth radius

e. Me is a non dimensional number of unit masses in the total mass of the Earth.

Substituting and rearranging variables we obtain:

$$G = \frac{\pi^2 * Re^2}{Me} * [m^3 u_m^{-1} s^{-2}]$$

From this elementary if not trivial operation we clearly can see the composition and meaning of G. As a dozen interpretations or rather verbal expressions of G are possible from any derived form of Newton law (such as equations for escape velocity, orbiting angular velocity etc), we will chose one that is exclusively based on the equation above.
G means no more and no less than the defining parameters present in the above equation namely:

'G (in the above specified system of units) is a dimensional constant obtained by multiplying the ratio of non-dimensional numbers by the product of units of measure in their respective powers. The ratio is:

$$\frac{\pi^2 * Re^2}{Me}$$

where

a. ***Re*** is known/defined ratio of Earth radius to reference one meter of length

b. ***Me*** is a ratio of Earth mass to the unit mass (yet to be defined)

c. π^2 is (approximate) experimentally correlated magnitude of Earth gravitational acceleration in reference location"

At this stage it can be stated that the physical meaning of gravitational constant is the function of constituting parameters as follows:

The physical meaning of ***G*** lies in the magnitude of gravitational acceleration approximately represented here as π^2, experimentally correlated to arbitrary unit of second and the unit of length (meter). The process of such correlation can be qualified as the <u>necessary</u> measurement of a physical quantity related to gravity and inertia, thus capturing the essence of these phenomena.

The value of ***Re*** is the result of surveying the Earth and does not reveal any significant physical quantity other than testing Earth geometry. If one select the mass of the Earth as unit mass, the value of G is <u>exactly defined</u> and no more physical contents can be derived from mechanical experiments, nor any mathematical transformation of Newton equation can. The question of what makes 'that big" object to accelerate bodies at 'that rate" at 'that distance" must remain unanswered at this stage.

If one wants to obtain the value of ***G*** in SI, one needs to compare the arbitrary selected standard of one kilogram and determine the value of ***Me***. The significance of the first direct force measurement performed by Cavendish is enormous as it was the proof that celestial bodies as well as small bodies follow Newton's law identically.

Recalling the equation:

$$G = \frac{\pi^2 * Re^2}{Me} * [m^3 u_m^{-1} s^{-2}]$$

we may notice that we have a full freedom in defining the unit of mass. Ritually we think about some object as reference, but this is not the only option. We may chose to define ***G*** as a non dimensional number, thus the unit of mass is necessarily:

$$m_u = \left[\frac{m^3}{s^2}\right]$$

Such definition has no direct reference to any particular object. The bonus is the elimination of ***G*** and rough estimate of ***Me*** (ideal earth). More spectacularly one can find the rough average radius of the moon orbit from the rotational period: 2360580s

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(Newton) to be 383630004.6 m, that is 0.09 % error wrt to published average value of 384000000 m.[1]

The measurements of **G** have the value since they allow us now to determine the mass of smaller objects since the Earth is not a practical standard for mass.

The major advantage of this operation is liberating physics from the elementary unit of mass – namely from the kilogram. This has a severe impact on other composite units as is discussed in the next chapter.

4 Kilogram-Free Metric System

4.1 Mechanical Units

Firstly it has been found beneficial to alter the usual form of gravitational law:

$$|F| = G' \cdot \frac{m_1 m_2}{4 \cdot \pi \cdot r^2}$$

for the reason of symmetry with Coulomb Law. Similar attempts have already been undertaken [11].

The consequences of replacing kilogram with $\left[\frac{m^3}{s^2}\right]$ are rather simple. Any composite unit containing kilogram has to have the kg symbol multiplied by $4*\pi*G\left[\frac{m^3}{kg \cdot s^2}\right]$.

Where **G** appears explicitly, it should be replaced by non-dimensional ***(1/4*π)***. This may appear as a cosmetic change and a nuisance, since **G** is not very accurately determined while masses in kilograms can be very precise. The practicality is not an issue here as the current system can be used for measurements anyway, but some interesting consequences for theoretical considerations. For instance Newton's law expressed as;

$$m_1 \frac{\partial^2 r(t)}{\partial t^2} = -\frac{m_1 m_2}{4 \cdot \pi \cdot r(t)^2}$$

is conceptually more convenient. One can try to understand the inverse square law as a result of increasing surface of the sphere with the distance rather than distance itself. Also after re-arranging the formula for acceleration:

$$m = 4 \cdot \pi \cdot r^2 \cdot g$$

one can attempt to define mass m seeing it in the first approximation as measured magnitude of gravity acceleration times the surface of the sphere intersecting given point and centered on ***m***.

[1] Newton (The principia Book III prop IV) used Moon data to demonstrate his inverse square law without the concept of **G** called Newtonian constant of gravity.

Also the question whether G changes over time can be transformed into a question whether material particles change in such a way that they attract other particles at a different rate with respect to time determined through other physical (electrical) phenomena.

In GR the nuisance constant $\kappa = \frac{8\pi G}{c^2}$ becomes $\kappa = \frac{2}{c^2}$ so the theory can now be pursued in pure space-time geometry domain with no explicit reference to gravitational properties as such.

For comparison we recall Planck's system of natural units where the gravitational constant is set to one (1), yet it does not really loose its dimension with Planck Mass constituting the unit. The advantage of these natural units is only convenient scaling, but not eliminating redundant reference mass as such.

At the time of writing the author found that such proposal for eliminating the base of unit of mass has already been presented by A. Chuykov [11] at conference in Petersburg in July 2000. This work however takes a different approach to electro-magnetic units described in the next paragraph.

$\frac{2}{c^2} = \sqrt{2}\left(\frac{1}{c}\right)^2$

4.2 Electro-magnetic Units.

The impact of eliminating the kilogram can be established by examining force equation for two electrons.

$$m_e \frac{\partial^2 r(t)}{\partial t^2} = -\frac{q_e q_e}{4 \cdot \pi \cdot \varepsilon_0 \cdot r(t)^2}$$

$\frac{8\pi G}{c^2} = \sqrt{2}\sqrt{\frac{\mu_0}{\varepsilon_0}}$

The left hand side no longer has the unit of kilogram which is still contained within ε_0. Since the speed of light c=299792458m/s and magnetic constant μ_0= 4*π*10^{-7} N/A^2

$\frac{8\pi G}{c^2} = 2\frac{\mu_0}{\varepsilon_0}$

$G = \frac{2c^2\mu_0}{4\pi\varepsilon_0}$

$$\varepsilon_0 = 0.010558719022930 32 \cdot \left[\frac{s^6 \cdot A^2}{m^6}\right]$$

When we require the constant ε_0 to be non-dimensional and equal one (1), as it was the case in Gauss system, and we find the replacement for Ampere as follows:

$$A = 9.731827077843336 \cdot \left[\frac{m^3}{s^3}\right]$$

And for the Coulomb:

$$C = 9.731827077843336 \cdot \left[\frac{m^3}{s^2}\right]$$

Surprisingly the new unit of charge has the same physical dimension as the unit of mass!

With no surprise comes that the magnetic constant is:

$$\mu_0 = \frac{1}{c^2} = \frac{1}{299792458^2} \cdot \left[\frac{s^2}{m^2}\right]$$

The elementary charge becomes:

$$e = 1.55921042825058910 \times 10^{-18} \cdot \left[\frac{m^3}{s^2}\right]$$

In a similar manner every other physical constant can be converted.

The mysterious ratio of electric to gravitational force is now:

$$\frac{e^2}{m_e^2} = 4.166358619454274 \times 10^{42}$$

Which can be seen as the effect of inherent properties of the electron rather then ratio of two forces in the system of two bodies.

The conversion table of metric to new system for SI derived units reveals that magnetic field induction unit is 1/s (that is as the unit for frequency or angular velocity) rather then complicated Tesla.

The electric field strength is in the units of acceleration rather than 'New ton over Coulomb". The same units characterize the strength of the gravity field. Most of electro-magnetic units are surprisingly simple and overall coherence is apparent.

Physical Quantity	**SI unit**	**SI Base Unit Representation**	**Conversion Formula**
mass	kg	kg	kg=8.38566477466*10^{-10} m^3/s^2
Current	A	A	A=9.731827077843 m^3/s^3
Force	N	kg*m/s^2	N=8.38566477466*10^{-10} m^4/s^4
Energy	J	kg*m^2/s^2	J= 8.38566477466*10^{-10} m^5/s^4
Pressure	Pa	kg/(m*s^2)	Pa= 8.38566477466*10^{-10} m^2/s^4
Potential	V	kg*m^2/(A*s^3)	V=8.61674247558*10^{-11} m^2/s^2
Charge	C	A*s	C= 9.73182707784 m^3/s^2

Physical Quantity	SI unit	SI Base Unit Representation	Conversion Formula
Capacitance	F	$A^2*s^4/(kg*m^2)$	$F= 1.12940906675*10^{11}$ m
Magnetic flux	Wb	$kg*m^2/(A*s^2)$	$Wb= 8.61674247558*10^{-11}$ m^2/s
Inductance	H	$kg*m^2/(A^2*s^2)$	$H= 8.854187817620*10^{-12}$ s^2/m
Resistance	Ω	$kg*m^2/(A^2*s^3)$	$\Omega= 8.854187817620*10^{-12}$ s/m
Magnetic field	T	$kg/(A*s^2)$	$T= 8.61674247558*10^{-11}$ 1/s
Electric Field	N/C	$kg*m/(s^2C)$	$N/C=8.61674247558*10^{-11}$ m/s^2
Mass density	kg/m^3	kg/m^3	$8.38566477466*10^{-10}$ $1/s^2$
Charge density	C/m^3	C/m^3	9.73182707784 $1/s^2$

5 Conclusions

1. Gravitational constant has no purpose of existence in physical equation being permanently blended into the concept of mass- both inertial and gravitational.
2. Electric constant has no purpose of existence being permanently blended together with gravitational constant into the concept of electric charge.
3. Magnetic constant remains dimensional and equal to inverse light speed squared.
4. Units of mass and charge are identical and suitable for kinematic comparisons.
5. Gravitational field strength and electric field strength have the same units of measure equal to unit of acceleration they, therefore directly comparable.
6. Magnetic induction has the dimension of angular velocity, therefore there exist a simple computational analogy to rotational motion:

$$E = B \times v$$
$$and$$
$$a = \omega \times v$$

An interesting relationship can be obtained from the formal properties of the electron: If one wishes to express the value of the static electric field strength of the electron at distance r_e (being the classical electron radius) by equivalent induced field due to 'induction" using equation:

$$E_e = B_e \times c$$

then the value of such 'induction" is dimensionally and numerically identical to the orbiting angular velocity at distance r_e due to gravitational field of the electron:

$$B_e = \omega$$

where ω is obtained from centrifugal/gravitational force equation:

$$\omega^2 \cdot re = \frac{me}{4 \cdot \pi \cdot re^2}$$

Note : G is embedded in me as previously indicated.

In the proposed time-length measurement system, inertial gravitational, magnetic and electric properties of the classical electron appear to be logically in harmony. Such view, with a bit of imagination can be propagated to any branch of physics contributing perhaps to the search of grand unification theory.